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A SLIDE RULE FOR ACTIVATION AND DECAY CALCULATIONS

By A. H. Snell and Thelma Arnette

The calculation of the strength of radioactive samples after neutron irradiation, followed perhaps by a period of decay, has become so much a matter of routine that it seems that a quick aid to calculation might be a time saver to those engaged in this type of work. The accompanying figures show how a slide rule could be constructed which would give answers to these calculations, including in most cases the correct power of 10, to an accuracy commensurate with the precision of most cross section and flux values. The expression to be evaluated is in general the product

$$nv\ \sigma\ M/A \times 6.06 \times 10^{23} (1-e^{-\lambda t_1})\ e^{-\lambda t_2}$$

in which nv is the neutron flux, σ the activation cross section, M the mass of the sample in grams, A its atomic weight, λ the decay constant of the induced activity, t_1 the irradiation time and t_2 the decay time subsequent to irradiation. This can be modified and condensed to the form

$$nv'\Sigma\ M\ (1-e^{-0.693t_1'})e^{-.693t_2'}$$

where Σ is the activation cross section per gram of normal element, and can be read from a table on the back of the slide rule for any of the one hundred and fifty or so activities usually encountered; t_1' and t_2' are respectively the activation and decay times, now expressed in units of the half-life of the activity concerned.

The operation of the rule can be understood with reference to Figure 1—A, B, and C, for which the following sample calculations are respectively set up:

A) 3.2 grams of strontium are activated for 30 days in an average slow neutron flux of 2.2×10^{11}. What is the strength of the induced 55-day activity? Using the C–D scales, 30 days is found to be 0.55 of a half-life. Reference to the table on the back of the rule (Figure 2)shows that strontium has an activation cross section of 2.8×10^{-5} cm^2 per gram. The end of the nv scale on the slide (viz. the 10^9 mark) is placed opposite 2.8×10^{-6} on the Σ scale. The cursor is then set at 2.2×10^{11} on the nv scale, and the slide is moved until 5.5×10^{-1} on the t scale is under the cursor line. (This takes care of the $(1-e^{-\lambda_1 t})$ factor). The left-hand end of the nv scale is then opposite the figure 1.93×10^6 when read from the $-dn/dt$ scale; this gives the number of disintegrations per second per gram. The nv scale can then be used again to multiply it by 3.2, giving the answer to the problem: 6.1×10^6 disintegrations per second.

B) 5.3 grams of silver are activated to saturation in an average flux of 4.4×10^{13}. What is the strength of the induced 2.3-minute activity? The end of the nv scale is set against the figure $\Sigma = 1.42 \times 10^{-1}$. In this case we find that we must use the right-hand end of the nv scale, and this means that the answer as given on the $-dn/dt$ scale will have to be multiplied by 10^5; the figure "$\times 10^5$" is inscribed at the right-hand end of the nv scale to remind the calculator that this is so. Since the $1-e^{-\lambda t}$ factor is unity, $(t = \infty)$, the position of 4.4×10^{13} on the nv scale can then be marked with the cursor, and multiplied directly by 5.3 to give the answer 3.3×10^{13} disintegrations per second.

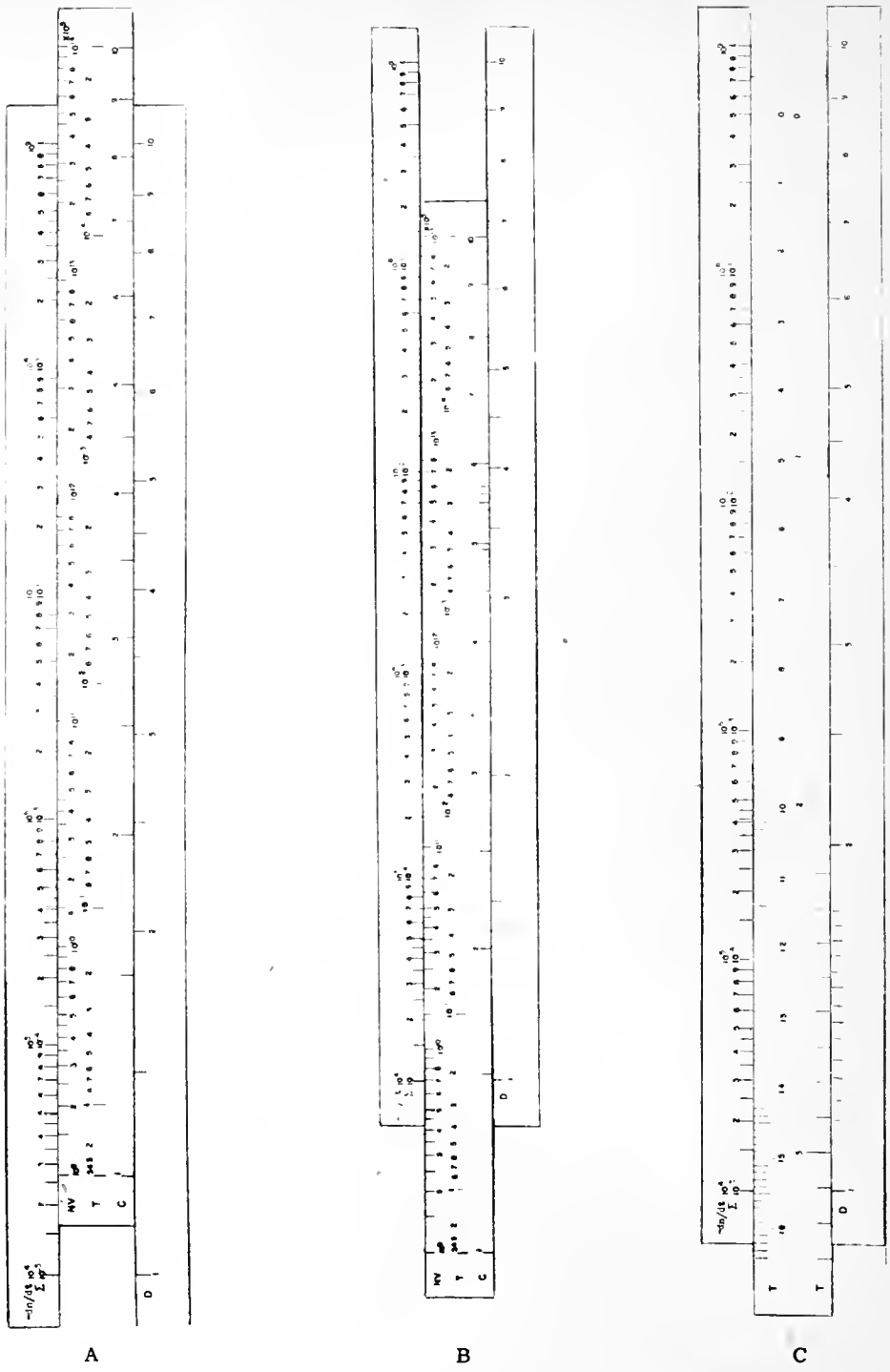

Figure 1. Slide rule for activation and decay calculations.

Element	Half-life	Σ(cm^2 per g of element)
H*	25 y	5.68
Li	0.88 s	$< 3.2 \times 10^{-4}$
C**	25,000 y	7.3×10^{-2}
N	8 s	$< 4 \times 10^{-9}$
O	31 s	1.7×10^{-8}
F	12 s	3.0×10^{-4}
Na	14.8 h	1.0×10^{-2}
Mg	10.2 m	1.34×10^{-4}
Al	2.4 m	5.2×10^{-3}
Si	17.0 m	1.0×10^{-4}
P	14.3 d	4.5×10^{-3}
S	87.1 d	2.1×10^{-4}
Cl	37 m	2.6×10^{-3}
A	110 m	1.88×10^{-2}
K	12.4 h	1.04×10^{-3}
Ca	8.5 d	$< 1.5 \times 10^{-6}$
Ca	180 d	2.0×10^{-4}
Ca	2.5 h	5.9×10^{-6}
Sc	85 d	3.0×10^{-1}
Ti	72 d	9.5×10^{-5}
V	3.9 m	6.0×10^{-2}
Cr	26.5 d	5.8×10^{-3}
Cr	1.3 h	1.6×10^{-6}
Mn	2.59 h	1.27×10^{-1}
Fe	47 d	1.1×10^{-5}
Co	10.7 m	7.5×10^{-3}
Co	5.3 y	2.3×10^{-1}
Ni	2.6 h	2.0×10^{-4}
Cu	12.8 h	2.1×10^{-2}
Cu	5 m	5.7×10^{-3}
Zn	250 d	2.4×10^{-3}
Zn	57 m	1.9×10^{-3}
Zn	13.8 h	5.0×10^{-4}
Ga	20 m	8.2×10^{-3}
Ga	14.1 h	1.13×10^{-2}
Ge	40 h	1.3×10^{-4}
Ge	11 d	7.9×10^{-4}
Ge	89 m	1.2×10^{-3}
Ge	12 h	4.6×10^{-5}
Se	115 d	1.5×10^{-3}
Se	19 m	2.0×10^{-3}
Se	57 m	1.3×10^{-4}
Se	30 m	4.3×10^{-5}
As	26.8 h	3.7×10^{-2}
Br	18 m	3.4×10^{-2}
Br	4.4 h	1.16×10^{-2}
Br	34 h	8.4×10^{-3}
Rb	19.5 d	3.71×10^{-3}
Rb	17.5 m	2.6×10^{-4}
Sr	2.7 h	9.7×10^{-4}
Sr	55 d	2.8×10^{-5}
Y	60 h	7.5×10^{-3}
Zr	63 d	4.8×10^{-4}
Zr	17 h	6×10^{-5}
Zr	6 m	1.1×10^{-4}
Cb	6.6 m	1.4×10^{-4}
Mo	67 h	5.9×10^{-4}
Mo	14.6 m	1.3×10^{-4}
Ru	42 d	2.2×10^{-3}
Ru	37 h	8.9×10^{-4}
Ru	4 h	7.3×10^{-4}
Rh	44 s	8.8×10^{-1}
Rh	4.2 m	7.5×10^{-2}
Pd	13 h	1.8×10^{-2}
Pd	26 m	4.8×10^{-4}
Ag	2.3 m	1.42×10^{-1}
Ag	22 s	2.88×10^{-1}
Ag	225 d	6.2×10^{-3}
Cd	2.5 d	1.6×10^{-3}
Cd	46 d	2.2×10^{-4}
Cd	3.75 h	5.4×10^{-4}
Cd	2 m	2.7×10^{-4}
In	48 d	1.45×10^{-2}
In	13 s	2.8×10^{-1}
In	54 m	7.9×10^{-1}
Sn	100 d	6.1×10^{-5}
Sn	9 m	2.0×10^{-4}
Sn	40 m	7.2×10^{-5}
Sn	26 h	3.7×10^{-4}
Sn	400 d	9.2×10^{-6}
Sn	10 d	5×10^{-5}
Sb	2.8 d	1.9×10^{-2}
Sb	60 d	5.5×10^{-3}
Te	9.3 h	7.1×10^{-4}
Te	72 m	2.07×10^{-4}
Te	32 d	2.4×10^{-5}
Te	25 m	3.8×10^{-4}
Te	30 h	$< 1.4 \times 10^{-5}$
I	25 m	3.2×10^{-2}
Cs	3 h	7.3×10^{-5}
Cs	1.7 y	1.17×10^{-1}
Ba	86 m	1.8×10^{-3}
La	40.0 h	3.7×10^{-2}
Pr	19 h	4.7×10^{-2}
Sm	21 m	4.8×10^{-3}
Sm	46 h	1.6×10^{-1}
Eu	94 h	2.98
Eu	6.5 y	1.55
Gd	9.5 h	8.9×10^{-3}
Gd	20 h	3×10^{-3}
Gd	8.6 d	2×10^{-3}
Tb	3.9 h	4.4×10^{-2}
Tb	72 d	4×10^{-1}
Ho	30 h	2.4×10^{-1}
Dy	1.4 m	1.5×10^{-1}
Dy	2.5 h	2.95
Tm	105 d	4.2×10^{-1}
Lu	6.6 d	3.4×10^{-1}
Lu	3.4 h	6.0×10^{-2}
Hf	46 d	1.2×10^{-2}
Ta	117 d	7.5×10^{-2}
Ta	16.5 m	1.2×10^{-4}
W	77 d	2.1×10^{-3}
W	23 h	3.6×10^{-2}
Re	90 h	1.37×10^{-1}
Re	18 h	1.64×10^{-1}
Os	32 h	2.1×10^{-3}
Os	17 d	7.0×10^{-3}
Ir	19 h	2.7×10^{-1}
Ir	1.5 m	6.5×10^{-3}
Ir	70 d	1.32
Pt	18 h	9.3×10^{-4}
Pt	3.3 d	3.7×10^{-3}
Pt	31 m	9.3×10^{-4}
Au	27 d	3.2×10^{-1}
Hg	51.5 d	2.3×10^{-3}
Hg	5.5 m	7.5×10^{-5}
Tl	4.23 m	2.6×10^{-4}
Tl	3.5 y	6.5×10^{-3}
Pb	3.0 h	7.0×10^{-7}
Bi	5.0 d	4.3×10^{-5}
Th	23 m	2.2×10^{-2}
U	23.5 m	6.9×10^{-3}

*From Li
**From N

Figure 2. Reference table on back of rule.

C) A sample of 0.5 curie strength is allowed to decay for 9.62 half-lives. What is its strength? To make decay calculations, the slide is turned over, revealing two linear scales. The upper one is needed for this problem, and by setting its 0 opposite 0.5 on the Σ scale one can read the answer 6.0×10^{-4} curies opposite the figure 9.62.

For more accurate computation for decay factors of less than 10, the lower t scale is supplied. t is again expressed in half-lives.

FISSION PRODUCT ACTIVITIES

The use of the rule can be extended directly to many of the fission products—namely, to the cases in which the growth is uncomplicated by chain relationships. This is done by defining Σ' as an effective cross section for formation of a particular fission product per gram of normal uranium undergoing slow neutron irradiation. In the use of the rule, the Σ's are set up on the Σ scale, and manipulation proceeds as in the case of (n,γ) activations.

DISCUSSION

It would be more convenient if the linear t-scales were on the same side of the slide as the nv scale. This could be done without crowding if the slide were made proportionately wider.

The cross section tables might well be printed on a card which slips into a holder on the back of the rule. Revised cards could then be supplied from time to time.

The circular type of slide rule would also be adaptable to these purposes.

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